Tonopah Minerals Technical Report

U.S. Department of the Interior
Bureau of Land Management
Battle Mountain District, Nevada

MINERALS TECHNICAL REPORT

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Tonopah Resource Area
Nevada

This document was prepared in support of the draft environmental impact statement containing the preliminary wilderness recommendations for the Tonopah Resource Area. Nine Wilderness Study Areas, totalling 488,890 acres of public land within Nye County, Nevada, are addressed in the draft environmental impact statement. This technical report outlines the methodology and criteria used to evaluate the potential for the occurrence of mineral and energy resources within the nine Wilderness Study Areas. This material was extracted by David L. Eddy, Geologist, Tonopah Resource Area, from MX Mineral Resources Survey, Nevada/Utah Siting Area, prepared by Fugro National, Inc. (1981).

METHODOLOGY FOR MINERAL POTENTIAL EVALUATION

Introduction

In early 1981, Fugro National, Inc. (now Ertec) completed and released, under contract for the U.S. Air Force, two reports on mineral resources surveys for the Nevada-Utah siting area for the proposed MX missile system. All of the Wilderness Study Areas within the Tonopah Resource Area were included within the region covered by these studies (see location map on following page). In these reports, Fugro used various criteria and data to determine the mineral potential of the study region for several commodities. Their methodology, data sources, and criteria for these evaluations are included in this report.

As Fugro's data and findings were felt to be very thorough, reliable, and the best information currently assembled and available, it was decided to utilize the probabilities which they had generated as a basis for the determination of wilderness designation impacts and their significance on potential mineral occurrences.

The two reports are:

Fugro National Inc., 1981, MX Mineral Resources Survey, Nevada/Utah siting area: Fugro National, Inc., 11 volumes.

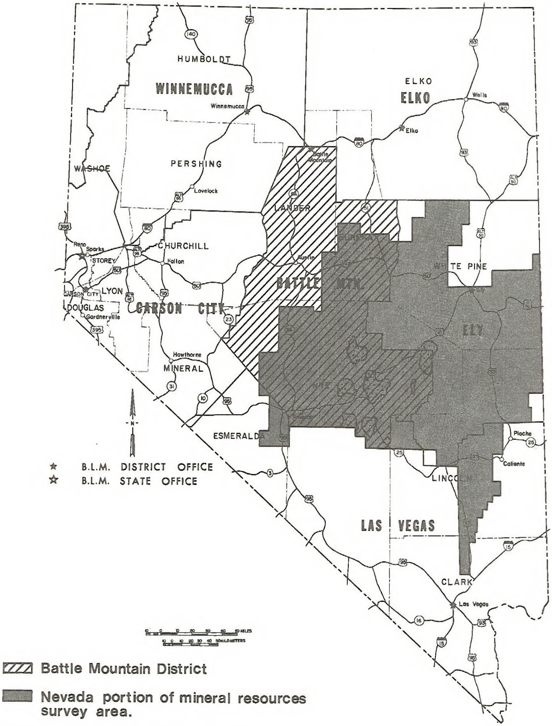
Ertec Western Inc., 1981, MX Mineral Resources Survey, seven additional valleys, Nevada/Utah siting area: Ertec Western, Inc. 4 volumes.

The following is from MX Mineral Resources Survey, Nevada-Utah Siting Area by Fugro National, Inc., (1981):

Methodology

The review of the metallic, nonmetallic, and energy commodities potential of the study area consisted of:

- o Research, procurement, and review of published and unpublished geologic and mineral-related literature and maps from federal and Nevada and Utah state government sources, including:
  - U.S. Geological Survey;
  - U.S. Bureau of Mines;
  - U.S. Bureau of Land Management;
  - U.S. Department of Energy;
  - Nevada Bureau of Mines and Geology;
  - University of Nevada at Reno; and
  - Utah Geological and Mineralogical Survey;



Battle Mountain District

Nevada portion of mineral resources survey area.

Wilderness Study Area Affected

MINERAL RESOURCES STUDY AREA

- o Procurement and review of geologic, mineral, and production-related data from professional groups, technical journals, trade associations, and private sources, including:

  - Rocky Mountain Association of Geologists;
  - Intermountain Association of Petroleum Geologists;
  - American Association of Petroleum Geologists;
  - Society of Economic Geologists;
  - Geological Society of America;
  - Society of Mining Engineers;
  - Nevada Mining Association;
  - Utah Mining Association;
  - Utah Petroleum Association; and
  - TerraScan Group, Ltd.;

- o Personal contacts with geologists affiliated with agencies and groups described above who are familiar with the geology and mineral (including oil and gas) occurrences within the study area;

- o Mailing of questionaires to 531 companies and individuals believed to be exploring or engaging in production activities within the study area soliciting their input regarding exploration commodity of interest, area of interest, and general, nonproprietary data regarding exploration results;

- o Field visits by geologists and engineers to document operating properties and areas of known intense exploration activity and mine development; and

- o Engaging the services of geologic and mineral economic consultants to provide reports of the mineral occurrences and potential, along with the geologic setting of the occurrences within their area(s) of expertise.

The geologic and mineral occurrence information obtained from the above described sources were reviewed, interpreted, and compiled into report form with accompanying maps illustrating interpretation of the relationship of the mineral commodity occurrences to intrusive and extrusive (volcanic) rocks, sedimentary environments and rock types, structural-tectonic features and trends, and geophysical anomalies. From these data, areas of potential for the various commodities investigated were outlined and presented in report and graphic format.

Potential Mineral Resource Areas

The types of potential resource environments and areas identified from the review of the mineral resources of the study area are as follows:

- Deeper zones beneath known developed deposits in many of the identified districts;

- Peripheral areas to identified districts based on geologic inferences;

- Areas outside of identified districts at intersections of favorable geologic structures either within or outside the interpreted mineral belts;

- Areas of favorable sedimentary lithofacies in conjunction with favorable structural setting and presence of indicator metals within ranges (in search of Carlin-type stratiform gold);

- Projections of identified districts and deposits based on geological inferences into adjacent valleys beyond range fronts beneath thin (<600 meters) pediment alluvial covers;

- Buried Paleozoic, Mesozoic, and Tertiary sediments underlying valley alluvial fill offer good to high potential for oil and gas occurrences throughout much of the study area because of the existence of favorable source and host rocks and the favorable degree of maturation of organic remains in the source rock; and

- Valley sediments from the range fronts to the playa lake areas offer an environment for occurrence of a number of commodities including uranium, beryllium, precious metals, placer, various brines and evaporites (lithium, boron, gypsum-anhydrite, and salt), clays, and zeolites.

The potential classification used in this report is defined as follows:

High Potential - High potential is assigned to areas that contain or are extensions of active or inactive properties which show evidence of ore, mineralization, and favorable geologic characteristics. All producing properties fall within this category.

Good Potential - Good potential is assigned to areas with several geologic characteristics indicative of mineralization, relatively lower economic value of past production, and similar environments but at greater distances from known ore and mineral occurences. This category may include areas adjacent to known districts or in mineral belts.

Speculative Potential - Speculative potential is assigned to areas having some favorable geologic parameters and inferences based on geologic models and analogies to known favorable environments. Increasing depth of alluvial cover over areas of potential deposits is also a consideration in this category, except in the case of oil and gas potential.

Low Potential - Low potential is assigned to areas that are outside any construed favorable geologic and mineral trend projections or are buried by over 1,500 meters of alluvium (except oil and gas).

The parameters that were considered in estimating the potential of areas include:

- Locations of the mineral deposits and districts;
- Past production history of the mineral districts;
- Location of mineral belts;
- Geologic phenomena related to mineral occurences:
  - Location of silicic igneous intrusives;
  - Location of silicic and intermediate volcanic rocks, centers, and calderas; and
  - Location of structural and tectonic trends;
- Presence of geophysical (aeromagnetic) anomalies;
- Depth of overburden cover to host rock;
- Reported company exploration activity; and
- Reported recent discoveries.

Gold and Silver - Types of Deposits and Geologic Environments

Gold and silver deposits commonly are intimately related in concentrations with variable ratios (from near nil to near 100 percent). The geologic environment of genesis, deposition, and structural control are sufficiently similar that both metals, along with many base metals, can be described together.

Within and immediately peripheral to the study area are a number of varying types of gold and silver ore occurrences in production, with past production, or with undeveloped reserves. In many deposits, overlapping or multiple geologic environments are present which makes environmental classification more complex. The geologic environments are described below. The description of the environments is taken from Beal (1980) and Erdosh (1980) with some modifications.

1. Replacement Bodies in Carbonates or Carbonate-Bearing Sediments
   These deposits are always sulfide-rich bodies high in silver and low in gold concentrations containing significant lead and/or zinc and possible minor copper. The deposits are highly irregular, closely controlled in shape and size by the host rock composition, particularly reactive carbonates, and by structures such as

faults, fractures, breccia zones, and the presence of dikes, all of which tend to channel the ore-bearing solutions. Genetically and spatially related Tertiary felsic intrusives may be the source of the ore-bearing late hydrothermal solutions and gases that were precipitated in the chemically suitable host rocks. Base metals are the principal constituents of this type of deposit.

2. Veins, Fissures, and Stockworks
This type of deposit is controlled by preexisting structures; i.e., fractures, fissures, faults, shatter zones, unhealed breccia zones, and openings along bedding planes. The vein-filling material that carries free gold, pyrite, and subordinate amounts of silver is quartz or quartz-adularia, in places with calcite. In order to form this type of ore occurrence, a hard competent host rock susceptable to fracture is necessary to create the conduit system for the mineralizing solutions, typically originating from a Tertiary felsic intrusive. The force of intrusion of the plutonic body is commonly responsible for fracturing the host rocks. Under favorable conditions, this type of environment may be spatially associated with replacement type of deposits. The epithermal "bonanza" deposits in highly altered Tertiary (Miocene) andesitic-dacitic to rhyolitic volcanic rocks, typified by the Goldfield and Tonopah districts, can be included in this classification. Most of the gold-silver vein and fissure deposits formed by hydro-thermal solutions in volcanic rocks, such as is characteristic of the Tonopah district, have limited vertical dimensions of 300 to 450 m. Commonly, these deposits exhibit metal zoning with gold decreasing and silver increasing with depth (Beal, 1980).

3. Disseminated in Igneous Intrusive Porphyritic and Adjacent Sedimentary Rocks
Minor disseminated quantities of gold and silver are associated with low-grade copper and molybdenum deposits in granitic and quartz monzonite stocks that have intruded sedimentary sequences. The precious metals are recovered as byproducts to the copper and molybdenum and the large tonnages mined at such deposits make their recovery worthwhile.

4. Volcanogenic and Volcaniclastic Rocks
In this type of occurence, low-grade, disseminated gold and silver occur in altered Tertiary andesites and dacitic flows and associated volcaniclastic rocks. The Goldfield District, immediately outside of the study area at the western boundary, contains this type of occurrence in addition to higher-grade, epithermal, bonanza-vein-stockwork type. Huge areas of argillized, alunitized andesites and dacite flows are known to carry low-grade values which, at some future time, may become economically viable (Erdosh, 1980).

Epithermal Disseminated-Replacement (Carlin-Type)

5. Low-grade, desseminated gold deposits occur in brecciated and highly thin-bedded argillaceous, siliceous dolomitic sedimentary beds. The deposits represent fine-grained replacement of the host dolomitic rocks by silica and minor pyrite. Associated with the gold are the heavy elements silver, arsenic, antimony, mercury, and barite. The deposits occur in proximity to sheared and thrusted zones and probably formed in response to hydrothermal processes caused by a shallow Tertiary igneous event.

   A number of deposits of this type and environment occur west and north of the study area. They are Jerritt Canyon, Alligator Ridge, Carlin Area (Lynn, Bootstrap, Bluestar, Maggie Creek, Pangana), Gold Acres, Cortez, Getchell, and Golconda deposits. Responses to the questionaire indicate that exploration of this environment is intense within the study area. A number of companies report encouraging results and discoveries not specifically identified.

6. Placer Concentrations
   Erosion of previously existing replacement, lode, and vein-fissure types of gold deposits has formed nearby placer deposits in slope and valley alluvium and colluvium. Several such deposits are being prospected and mined on a part-time basis within and immediately peripheral to the study area at the Osceola, Lincoln, Manhattan, and Tonopah Districts.

Gold and Silver - Review of Potential

Because of the close relationship of the gold and silver and base metal occurrences and environments within the study area and because most of the gold and silver occurrences are generally subordinate to the base metal occurrences, the review of the potential for gold and silver will be described in the Base and Ferrous Metals section. An important exception is the epithermal disseminated-replacement (Carlin-type) gold deposits, with no economic base metal association, which will be described in this section.

The general parameters to determine a region's disseminated gold potential are listed below. If an area has a number of these parameters, characteristic of Carlin-type deposits, it should be considered suspect for stratiform disseminated gold.

The parameters include:

- Host rocks with a general lithology ranging from argillaceous to dolomitic brecciated carbonates and siltstone which may be locally carbonaceous and silicified;

- Major thrust and normal fault zones in favorable host rocks where the structures provide channels and conduits for leaching and mineralizing hydrothermal fluids;

- Areas of volcanic and magmatic activity as high potential source areas for the mineralizing fluids;

- Known gold occurrences delineating positive areas of mineralization;

- Occurrences of arsenic, antimony, and mercury as an indication of favorable geochemical environments; and

- Jasperoid and silicified zones in carbonates as an indication of replacement by hydrothermal activity.

The criteria used to designate potential host rocks for Carlin-type deposits are difficult to apply to any specific formation due to facies changes and local lithologic variation. The formation may be favorable in one area and have less potential elsewhere. Following the pattern of previous discoveries, rocks of Cambrian through Jurassic age should be considered. In the study area, the lack of Mesozoic sedimentary rocks, because of erosion and nondeposition, dictate an emphasis on the Paleozoic sediments, particularly the lower and middle Paleozoic carbonates.

Some of the formations designated by Joseph Tingley and Harold Bonham of the Nevada Bureau of Mines and Geology with favorable lithologic characteristics, at least on a local basis, are the Emigrant Springs Formation and the Windfall Formation, both of Cambrian age and the Devonian-Mississippian Pilot Shale, as well as the Mississippian Joana Limestone and Chainman Shale. Some of the formations have stratigraphic equivalents with different names that also are favorable. Other formations in the vicinity of the study area that are potential host rocks in a favorable hydrothermal, structural, and geochemical location are listed below:

- Cambrian Notch Peak Formation (Windfall and Nopah Formation);

- Cambrian Secret Canyon Shale (Emigrant Springs Formation) upper portion;

- Ordovician Pogonip Group;

- Ordovician Fish Haven Dolomite;

- Silurian Roberts Mountain Formation;

- Devonian Guilmette Formation;

- Devonian Rabbit Hills Limestone;

- Devonian-Mississippian Eleana Formation (Pilot Shale); and

- Permian Gerster Limestone of the Park City Group and other unnamed Permian limestones.

The possibility for occurrence of disseminated gold deposits in a geologic setting such as the study area is enormous. Regionally, the western and northern portions of the study area in Nevada appear to offer the best opportunity for the discovery of other Carlin-type deposits. This assumption is based on a greater frequency of igneous intrusive and volcanic activity, aeromagnetic anomalies, orogenic belts, and proximity to known similar deposits. Reported company exploration activity is concentrated in this area.

<u>Mercury - Types of Deposits and Geologic Environments</u>

In the Belmont-Barcelona district in Nye County, the chief mercury mineral is cinnabar occurring in quartz-barite veins in a Cretaceous granitic intrusive and also in tabular bodies in Lower Cambrian quartzitic strata. The mercury depoists may be related genetically to Tertiary volcanism (Mardirosian, 1974). Other occurrences of mercury are located in the Tybo district, in Nye County, where the mercury occurs in veins and disseminations in Tertiary argillized rhyolite tuffs (Mardirosian, 1974)

In general, mercury is restricted to near-surface environments in areas of relatively low-temperature, volcanic hot spring activity, representing the waning stage of volcanism. Suitable fractured host rocks are required. Andesitic or rhyolitic tuffs are common host rocks. In limestone occurrences, the cinnabar replaces the host rock forming small but high-grade ore bodies. Mercury also occurs in opalite which is formed by the silicification of rhyolite tuff.

<u>Mercury - Review of Potential</u>

Only the extreme western portion of the study area near Tonopah and Manhattan and including the area to the southwest of a line roughly connecting the Belmont and Kawich districts appears to be favorable for the discovery of new mercury deposits of a size similar to previous discoveries. This northwest-southeast trending line approximates or parallels the northeast boundary of the Walker Lane Lineament. The best opportunity for the discovery of significant mercury deposits is considered to be west of the study area. Caldera environments in the study area may be receiving consideration for their mercury potential based upon the New Cordero Mine which occurs in a stratiform environment within the McDermitt Caldera along the Nevada-Oregon border.

<u>Platinum-Group Metals</u>

The potential of platunim metal occurrence in the study area is very low. Accordingly, only a brief statement is presented.

Significant ore deposits of the platinum-group of metals occur within mafic and ultramafic intrusives and layered complexes and in placers derived from such deposits. No environments of this type are known to be present in the study area and the likelihood of discovery of such an environment is remote (Erdosh, 1980).

Base and Ferrous Metals - Types of Deposits and Geologic Environments

Base and ferrous metals, together with associated coproduct and by-product gold and silver, occur in a variety of geologic environments in eastern Nevada. Many of these environments have been described in the precious metals section of this report, but for completeness, the environments most pertinent to the base and ferrous metals are summarized in this section.

The base and ferrous metal environments include:

- o Disseminated, low-grade occurrences of copper and molybdenum present in quartz monzonite intrusives. By-product values of gold, silver, lead, zinc, tungsten, and antimony commonly are present.

- o Fissure veins, stockworks, and breccia fillings in quartzite, carbonate, and shale beds, typically in close association with intrusive rocks, containing a wide suite of base, ferrous, and precious metals as coproducts and/or by-products.

- o Irregular-shaped replacement ore bodies in host carbonate-bearing sediments in places associated with felsic intrusives. Lead and zinc are the principal ore commodities, but significant amounts of silver, copper, tungsten, manganese, and gold frequently are common.

- o Contact zone, skarn, and tactite deposits within carbonate-intrusive contact zones containing a variety of metals, among them tungsten.

- o Vein, replacement, and contact-zone deposits of various base, ferrous, and precious metals associated with acid and intermediate volcanic dikes, sills, and shallow intrusive equivalents.

Base and Ferrous Metals - Review of Potential

This review of the potential includes all metals, precious, base, and ferrous, because of the close relationship of their occurrences in most of the identified mining districts throughout the study area. The only exception is the low-grade disseminated Carlin-type gold deposits which, because of their geologic habit are described in the gold and silver section of this report.

The rock types (intrusive, volcanics, and sediments) present beneath the valleys within the study area are similar to those exposed in the adjacent ranges. Many of these rock units undoubtedly host precious-base, and ferrous metal deposits, some representing downfaulted portions of deposits present along the range fronts, whereas others represent separate deposits within favorable environments or trends similar to those in the adjacent ranges.

The valleys that straddle major metal mineral belts, or structural, intrusive, volcanic, and aeromagnetic anomaly trends, particularly those associated with metal deposits in the adjacent ranges, are interpreted to have speculative, good, and high metal potential. The depth of burial is one of the factors controlling the classification of assigned potential as it ultimately determines economic viability. Other economic factors applicable to any deposit are size of the ore deposit, value of the commodity, and cost of extraction.

Potential is also assigned to zones peripheral to the mining districts that have not received adequate exploration to properly assess the metal potential. Special consideration is given to the basinward direction from the proven deposits within the range fronts and beyond, if geologic trends justify.

The relationship between metallic mineral deposits and various geologic features have been discussed previously in this report. In order to consider as many parameters as possible in assigning potential to a given area, the parameters listed in the following table were plotted on a base map and each parameter given a numeric weitht (shown adjacent to each parameter in the table). A 25-square kilometer grid was then superimposed upon a base map and a number given to each grid square equal to the sum of all of the weights of parameters occurring within that square. The resultant number grid was contoured and potentials assigned as follows: 0 - low; 1 to 2 - speculative; 3 to 4 - good; 5 and greater - high. In the valley areas these potential estimates were then modified by the interpreted depth to bedrock. Areas of a given potential lying between 600 meters and 1500 meters deep in the valley areas were lowered one potential category and all valley bedrock areas lying below 1500 meters were assigned a low potential.

Because of the absolute correlation of mining districts with economic mineral deposits, they are weighted the most heavily of any parameter considered. All operating properties within the study area are located in organized mining districts. To determine an area of influence that should be assigned to each mining district, the maps of the metallic mineral occurrences of Larson and others (1977) were utilized. Those clusters of occurrences coinciding with the named mining districts and not already counted as separate occurrences were outlined as the area comprising the various districts. Each such outlined district area was measured by planimeter and expressed in square kilometers. The average area was 37.78 km^2 per district and this number was rounded off to 40 km^2 per district.

PARAMETER	WEIGHT
Volcanic Center	1
Volcanic Caldera Perimeter Area	1
Granitic Intrusive	1
Metal Occurrence not Included in a Mining District (from Larson and others, 1977)	1
Positive Aeromagnetic Anomaly ($\leq$10,900 gammas)	1
High Positive Aeromagnetic Anomaly ($\geq$11,000; $\geq$11,200 gammas in SW mafic volcanic area)	2
Industry Discovery or Active Exploration	1
Mineral Belt	1
Mining District (area of influence: 40 km^2)	
Past Production (in millions of dollars)	
Less than 1	2
1 to 10	3
10 to 100	4
100 to 1,000	5
Greater than 1,000	6

Uranium - Types of Deposits and Geologic Environments

Uranium deposits within the study area occur associated with silicic intrusive and extrusive rocks or as peneconcordant bodies or veins in lake sediments, volcanic tuffs, and volcanic clastics and sediments (Cohenour, 1980a and b).

Many uranium occurrences in the Basin and Range Province show spatial (and probably genetic) association with relation to volcanic caldera structures. Such structures are prevalent within the study area. A deposit, estimated to contain 2,250 to 4,500 metric tons of U_3O_8 of 450 grams per ton approximate grade, has been outlined by Placer Amex in the northern part of the McDermitt Caldera along the Nevada-Oregon border. Chevron Resources is reported to have outlined a significant deposit in a silicified and brecciated fault structure in rhyolitic ash flow in another portion of the McDermitt Caldera. Mercury, uranium, and lithium are in close association within tuffaceous rocks of the caldera (Rytuba, in Newman and Goode, 1979).

The large Pena Blanca (Aldama) uranium deposit in the state of Chihuahua, Mexico, contains a proven reserve in the range of 4,500 metric tons of U_3O_8 with a possible potential reserve in the 45,000 metric tons range (Mexico Atomic Energy Commission, communication, 1977). The environment of this major deposit is analogous to the geologic setting present in portions of the Basin and Range Province in the United States, including areas within the study area. The deposit occurs predominantly in rhyolitic flows and plugs and welded tuffs associated with major fault and fracture zones, perhaps related to caldera development. Commercial grade mineralization also occurs in limestones beneath the volcanics.

Larson and others (1977) summarizes favorable uranium environments that could be present in the region, including the study area:

- Topographic and/or structural basins which either contain or are immediately adjacent to Tertiary rhyolitic volcanic rocks (potential source rocks) and which contain hydrocarbon reservoir rocks;
- Topographic and/or structural basin or basin-margin environments in which the potential host rocks consist of zeolites and associated montmorillonites formed either by devitrification of tuffs or as sediments in alkaline closed lakes;
- Topographic and/or structural basin-margin environments adjacent to potential volcanic or plutonic source rocks containing known uranium deposits.
- Topographic and/or structural basin and basin-margin environments where adjacent older rocks contain numerous uraniferous deposits;
- Topographic and/or structural basin-margin bajada and alluvial fans which commonly contain carbonaceous materials;
- Topographic and/or structural basin and fluvial sediments presently preserved as relics; and
- Caliche and calcrete subenvironments in basins where potential volcanic source rocks are available.

Uranium - Review of Potential

Cohenour (1980b) states that the assessment of the uranium potential of the study area should consider the following factors:

- The areal distribution of known uranium deposits and anomalies;
- The areal distribution of igneous intrusives and extrusive terrains;
- The areal extent and geometry of intra- and inter-mountain basins;
- The size and areal distribution of known and suspected calderas;
- The hydrology of the region (particular emphasis should be given to the geologic setting of recharge zones as well as the attendant subsurface movement of ground water caused by tectonic and thermal activity);
- The analyses of syngenetic environments, their extent, position relative to paleo and present physiography (hydraulic gradients), and their original and/or residual uranium content;

- o The analyses of epigenetic uranium occurrences or anomalies with emphasis on radiometric versus chemical analytical balance (equilibrium)(radiometric analyses higher than chemical analyses can indicate uranium movement either down or toward the low side of a hydraulic gradient);

- o Where possible, studies and investigations of inter-basin sediments should be considered, especially indices of porosity and permeability (emphasis should be placed on the geometry of intra-sedimentary unconformities and the possible interbedding or intrusion by uraniferous igneous source rocks);

- o The analyses of ground water in aquifers and subsurface reservoirs, as well as playa waters, especially subsurface brines which may possibly be stratified and/or areally differentiated due to differences in brine densities and/or the source of subsurface peripheral recharge; and

- o Certain regional aspects of the Great Basin which may enhance subsequent determination of target areas for the discovery of low- and intermediate-grade deposits.

Two east-west belts contining greater densities of uranium occurrence are present across the study area. One trend extends from the Sheeprock Mountains and Desert Caldera area westward and includes the Keg and Thomas Calderas, Honeycomb Hills, and Fish Creek Mountains. A second belt extends from the Red Hills caldera at Marysvale, Utah to the east Walker area in western Nevada. In Utah, this broad belt is known as the Marysvale-Beaver uranium trend (Cohenour, 1980b). Within these two belts, the presence of fluorine and/or beryllium mineralization associated with Tertiary rhyolitic volcanics is a guide to uranium mineralization (Larson and others, 1977).

The uranium potential described and outlined takes the following into consideration: 1) the rock units present at the surface and units interpreted to be present in the subsurface, 2) presence of high supergene uranium occurence, 3) presence and density of epigenetic uranium occurrences, 4) analogies to producing uranium environments, 5) structural setting, and 6) hydrologic and hydrodynamic regimes.

Beryllium - Types of Deposits and Geologic Environments

Beryllium in the form of bertrandite forms large economic deposits in a rhyolite ash or tuff bed at Spor Mountain, Jaub County, Utah. Other minerals occuring with bertrandite contain uranium, fluorspar, lithium, and manganese. The rhyolite tuff occurs in a sequence of Tertiary beds comprised of rhyolite and altered rhyolite overlying a thick sequence of limestone and dolomite of Paleozoic age. The ore deposits are tabular, lens-like masses in configuration, spatially and perhaps genetically related to faults.

The close relationship of low-grade uranium concentrations to the economically recoverable beryllium is of interest not only because of being an exploration guide to beryllium and its recovery as a by-product of beryllium mining, but because of genetic implications. The Spor Mountain deposits are generally classed as epithermal by a number of workers including W.R. Griffitts (in Brobst and Pratt, 1973; and Griffitts and others, 1962, 1963). However, the uranium may be derived from leaching of the volcanic tuffs during stages of devitrification and reconcentrating in favorable structural, lithologic, and chemical environments. A similar origin for the bertrandite and also for the lithium can be envisioned.

Other geologic environments within or immediately peripheral to the Utah portion of the study area that contain beryllium are pegmatite or pegmatitic deposits in granitic intrusive rocks in the Deep Creek Range, Sheeprock Mountains (Cohenour, 1980a), and in the Mineral Mountains (U.S. Geological Survey and others, 1964) in Jaub and Beaver Counties, Utah. Beryllium-bearing veins containing beryl and phenacite are present in White Pine County, Nevada, in the Mount Wheeler area (Minerva District). The veins, containing quartz, cut Cambrian limestone (U.S. Geological Survey and others, 1964).

Beryl- and fluorite-bearing veins occur in the Roberts Mountain Thrust Zone between the Eureka Quartzite and Silurian limestone and dolomite in the Fish Creek Range southwest of Eureka, Nevada (Roberts and others, 1967). The area of mineralization is extensive, and future production is a possibility depending upon demand and pricing parameters.

In White Pine County, 0.1 percent BeO concentrations occur in a bleached, altered quartz monzonite in the Egan Range and may represent epithermal-type mineralization (U.S. Geological Survey and others, 1964).

Beryllium - Review of Potential

Cohenour (1980a) indicates the likelihood for additional beryllium potential within the study area is generally confined to the Utah Beryllium Belt in the tuffaceous sediments in the valleys. Much of central and eastern Nevada, including portions of the study area, is in the largest nonpegmatitic beryllium province in North America (W.R. Griffitts in Brobst and Pratt, 1973). Included in this province are the beryllium occurrences at Mount Wheeler and those in the Fish Creek Range southwest of Eureka (U.S. Geolgical Survey and others, 1964). These two areas have had only minor production in contrast to the large production at Spor Mountain, Utah.

Regional geochemical exploration being conducted by many companies throughout the study area may discover other epithermal-type beryllium occurrences heretofore undetected by previous conventional reconnaissance. Future discoveries may be found in altered silicic intrusive rocks and in altered volcanic tuffs similar to Spor

Mountain. The altered rhyolite tuffs and intrusives occurring within the Wah Wah-Tushar Mineral Belt in Beaver County, Utah and westward within the Pioche Mineral Belt in Lincoln County, Nevada, show strong geologic analogies to the Utah Beryllium Belt which contains the Spor Mountain deposits.

Nonmetallic and Industrial Minerals - Epigenetic Environments

Epigenetic mineral deposits are formed through hydrothermal or metamorphic processes which alter the original host rock and/or introduce the economc constituent in a mineralizing solution. Nonmetallic and industrial mineral deposits formed in this way include most of the commercial clays, reconcentrated minerals like lithium carbonate, and introduced mineral deposits such as fluorspar, zeolite, barite, and many gemstones.

Nonmetallic and Industrial Minerals - Occurrences, Distribution, and Production

The epigenetic occurrences are described by specific commodities. The commodities with a past production history are given priority in this report.

Barite

Eighty-four percent of the barite production in the United States comes from Nevada, and the United States imports 1.4 million tons in addition to the 2.0 million tons of domestic production (Lefond, 1980).

Most of the barite occurs in a belt that coincides with the Antler Orogenic Belt which crosses the western portion of the study area. The deposits are fissure vein and replacement types of hydrothermal origin occurring in carbonate host rocks of varying age.

In the Nevada portion of the study area, barite is present in the Ellendale District, Warm Springs Mine, and the Jumbo Mine. The Warm Springs Mine is located east of the interpreted east limit of the barite belt.

Total production of barite from within the study area has been small relative to the large barite deposits and production north of the study area in Elko, Eureka, and Lander Counties, Nevada, and is estimated to have been less than 100,000 tons.

Fluorspar

Many of the numerous occurrences of fluorspar in the study area are not economic deposits today but may represent a future potential source of fluorspar depending on market demand.

Because fluorspar can form in a wide range of pressures and temperatures, it is present in many different geological environments of both epithermal and mesothermal types. Fluorspar occurs in pyrometasomatic, pegmatitic, sedimentary phosphate, hydrothermal, and Tertiary lacustrine deposits. Economically, the most important fluorspar occurrences occur as veins and replacement bodies in reactive carbonate rocks, stockworks, breccia pipes, or disseminated deposits, and are commonly associated with quartz, calcite, and pyrite.

Much time and energy has been devoted to fluorspar exploration resulting in many occurrence discoveries. Papke (1979) defines a fluorspar belt that covers almost all the study area in Nevada and extends into Utah in the Wah Wah-Tushar Mineral Belt and Spor Mountain areas.

There are approximately 21 fluorspar mines and prospects in the Nevada portion of the study area of which none are currently producing.

- In Eureka County, the Bisoni or Fish Creek Prospect has several large low-grade fluorspar bodies. There has been no production.
- The White Pine Prospect in Nye County contains a metamorphosed limestone with disseminated fluorspar mineralization. The Keystone or Wall Mine in the Manhattan District has breccia pipe mineralization and unknown production. The largest concentration of fluorspar in Nevada is in the Quinn Canyon District, Nye and Lincoln Counties. This district contains 17 mines and prospects with past production in Tertiary volcanics and Paleozoic limestones. Exploration and development is hindered by the steep terrain, isolated location, and distance from a railroad. Total production from this district is estimated to be 29,500 tons (Papke,1979).
- In White Pine County, Nevada, the Rattlesnake Heaven Prospect is a replacement fluorspar deposit in Spring Valley. The Sawmill Canyon Prospect in the Egan Range has vein fluorspar present that may be near a contact between rhyolite and limestone. A few tons of fluorspar were produced prior to 1961 (Papke, 1979).

Clays

Clays are secondary minerals derived by hydrothermal and supergene alteration of many rock types and exist as kaolin, ball clay, fire clay, bentonite, Fuller's earth (mostly montmorillonite), and other speciality clays. Commercial clay deposits within the study area are primarily kaolins and bentonites derived from the alteration of tuffaceous strata or possibly some of the carbonate formations. Industrial clays can also be found in Pleistocene Lake Bonneville deposits.

South of Frisco, Utah, a kaolinite deposit is found in association with alunite. In the Nevada portion of the study area, montmorillonite is found at Bristol Well in Lincoln County. Refractory clay is found at the McDonough deposit east of Ely on the north boundary of the study area in White Pine County.

Gems and Semiprecious Stones

Gem and semiprecious stone mines in the study area have been operated by individuals rather than large companies. Precious gems are not known to exist in the study area, but semiprecious gems are fairly plentiful.

Deposits of gem material in (the Nevada portion) of the study area are:

- o Belmont Mining District - Turquise;
- o Warm Springs District - Turquoise.

The semiprecious gem resources have not yet been systematically evaluated, and new discoveries will probably depend on the efforts of the small operators and hobbyists (Lefond, 1980).

Refractory Minerals

The refractory minerals consist of:
1) the aluminous silicate minerals-kyanite, andalusite; and
2) the magnesium minerals-magnesite and brucite.

Kyanite occurs in regionally metamorphosed aluminous rocks and andalusite is found in highly aluminous rocks which have been locally altered by granitic intrusives. The general absence of metamorphic rocks in the study area precludes occurrences of these commodities.

West of the study area at Gabbs, Nevada, a significant deposit of magnesite and brucite is being mined for the magnesium content. Mineralization occurs when limestone, dolomite, or serpentine are enriched in magnesium by the introduction of magnesian waters from nearby intrusives. In the Nevada portion of the study area, magnesite has been produced from mines in the Currant Creek District where it occurs as disseminated grains, nodules, and veins in a calcareous Tertiary tuff.

Alunite

Alunite represents a future major source of aluminum, potassium, and sulfur. The largest alunite resources in the United States are in Utah. One such deposit estimated to contain over 100 million tons of recoverable alunite is located in Beaver County, in the White Mountains-Pine Valley area. Indicated and inferred reserves are estimated to be many times the proven reserves (Earth Sciences, Inc., communication, 1980). In this deposit, fine-grained alunite, kaolinite, and quartz replace the primary minerals of a Tertiary ash flow tuff (Lefond, 1980). There has not been any production from this property to date.

Alunite has been mined as an alteration coproduct in some metal mines in the study area, including the Boyd Mines in the Currant Creek District.

Zeolites

Saline alkaline lake deposits which are common in the study area are now recognized as an ideal environment for zeolite formation. The occurrence of volcanism to supply the reactive materials, the closed basins, and the arid climate make the study area a prime exploration target for zeolites.

Natural zeolites form by the reaction of volcanic glass with connate water trapped during sedimentation in saline alkaline lakes. Most zeolites used in industry today are expensive and produced synthetically.

Of the 40 known zeolite species, six are common in the Basin and Range: analcime, chabazite, clinoptilolite, erionite, mordenite, and phillipsite. These minerals are all hydrous sodium aluminum silicates with varying amounts of potassium and calcium replacing sodium. Some of the lacustrine deposits containing zeolites also contain bedded saline minerals such as trona, nahcolite, and halite (Ronald C. Surdam in Newman and Goode, 1979). The use of zeolites in industry is expanding, and natural occurrences may supplant synthetic production if quality and grade prove them more economic. This possibility makes natural zeolites an unknown but very prospective commodity for near-term development.

At the present time, an analcime deposit has been located near Currant, Nevada, and deposits of clinoptilolite and mordenite are located near Tonopah. Papke (1972) also indicates the presence of clinoptilolite just south of Caliente.

Sulfur

Sulfur occurs in its native form associated with hot springs and fumaroles, combined with metals to form metallic sulfides, and as hydrogen sulfide (H_2S) in "sour" natural gas.

In the Nevada portion of the study area, there are no known native sulfur deposits nor have pyrite and sour natural gas been produced for their sulfur content.

Other Epigenetic Nonmetallic Minerals

Commercial occurrences of talc, vermiculite, and asbestos are not known in the study area. The metamorphic environments in which these commodities occur do not appear to be present on a scale to form viable deposits.

Nonmetallic and Industrial Minerals - Syngenetic Environments

Syngenetic deposits of nonmetallic and industrial minerals are formed simultaneously with the host rock or as an economic unit themselves. These deposits may be sedimentary (i.e., gypsum, halite, etc.) or volcanic (i.e., perlite, light rhyolite aggregate, etc.) in origin, but they require no alteration or additional mineralizing source to account for their presence as an economic deposit.

Nonmetallic and Industrial Minerals - Occurrences, Distribution, and Production

The syngenetic occurrences are described by specific commodities. The commodities with a past production history are given priority in the report.

Perlite

Perlite is a hydrated volcanic glass that expands upon heating. The major perlite deposits of the study area are located in Lincoln County, Nevada.

Total production from Lincoln County through 1951 was approximately 180 million tons (Tschanz and Pompeyan, 1970). Annual production has fluctuated around 25,000 to 35,000 short tons per year, however, total production figures to date are not available.

Increasing use of perlite for insulation in light concrete applications is expected to result in continued exploration and development of these deposits.

Pumice, Pumicite (Light Rhyolite)

Pumice and pumicite are silicic volcanic rocks, dominantly glass, formed as gaseous ejecta from rhyolitic volcanic domes or as layered ash-fall deposits either air or water deposited. They are highly porous and vesicular and of very low density which makes them ideal as light aggregate and nonreactive light fillers for such things as paint and cement. There are no producing pumice or pumicite deposits in the study area at present, though deposits of these materials do exist. Many of the ash-flow tuffs and rhyolitic volcanic centers in Nevada are likely sources for these commodities if future market demands warrant their exploration and development.

Silica, Dimension Stone, Crushing Stone

Silica sands and massive quartzite occurrences are widespread in the study area, as are limestones suitable for commercial lime and cement use. In Nevada, quartz (silica) has been produced from the Prospect Mountain Quartzite at Caliente. Star Dust Mines, Inc. in White Pine County, has produced a Cambrian schistose quartzite for dimensional stone. Other dimension stone and silica mines are present in Clark County just south of the study area.

Limestone suitable for crushing and refinement has two principal uses: 1) cement, and 2) chemical lime and calcium. Cement-grade limestone can have more impurities than chemical grades and is therefore more abundant, but limestones of both grades are fairly abundant in middle and upper Paleozoic carbonate rocks in most of the central study area.

Large amounts of chemical-grade limestone are used in the steel and copper smelting industry in Utah, but sources for this lime close to Salt Lake City have prevented development of these resources in the study area. Other markets have also been supplied from more local sources, so there is no current production of limestone in the study area.

Salines - Brines

The playa lakes of the Basin and Range Province have past production of such minerals as sodium chloride (salt), borax, sodium carbonate, sodium sulfate, and lithium. These deposits have now been recognized as a potential source of potash, magnesium, calcium chloride, fluorine, tungsten, uranium, zeolites, clays, and other materials (Papke, 1976).

The conditions for the formation of a playa are a topographically closed depression, an interior drainage system, and an arid or semi-arid climate (Papke, 1976). Basin and range faulting created the closed basins and interior drainage in many of the study area valleys. After basin and range faulting, sedimentation and the arid climate reduced the large shallow lakes of the study area to alkaline and saline modern-day playas.

Evaporites, or saline minerals, are chemically precipitated when the water becomes saturated. The evaporites occur as crusts, small masses, buried beds, or as surface and near surface brines (Papke, 1976). The playa lakes become more saline and alkaline toward the lake centers resulting in zoning of the salts. Little is known about the playas of Nevada and Utah, with the exception of the Silver Peak Marsh west of the study area, which is the world's largest source of lithium.

Lithium, the lightest known metal, is now used extensively in industry. Little information is available on the distribution of lithium in the playa deposits of the study area, but the current sharp increase in demand for lithium can be expected to result in intensified exploration and probable new discoveries of lithium in the playa sediments and brines of the study area. Of the many evaporative minerals, halite (salt or sodium chloride) is generally the most abundant. A small amount of salt has been produced from the Railroad Valley, Butterfield Marsh, and the Spring Valley deposits in the past, but no current production is reported from the study area.

Sodium carbonate (soda ash) occurs in many minerals, but commercial sources are from trona, gaylussite, or brines. A large deposit of gaylussite occurs with salt in the Railroad Valley, Butterfield Marsh deposit. It is not presently a commercial source, but may be in the future (Papke, 1976).

The brines may be used in the future as a source of salt, sodium sulfate, magnesium and potassium chemical, lithium, and bromine (Whelan, 1969).

Other Syngenetic Nonmetallic and Industrial Minerals

Borates, diatomite, gypsum, anhydrite, potash, and phosphates are not known to occur in economic deposits within the study area. Future exploration of evaporite deposits in the study area may reveal commercial deposits of one or more of these commodities.

Oil and Gas - Geologic Environment and Production Horizons

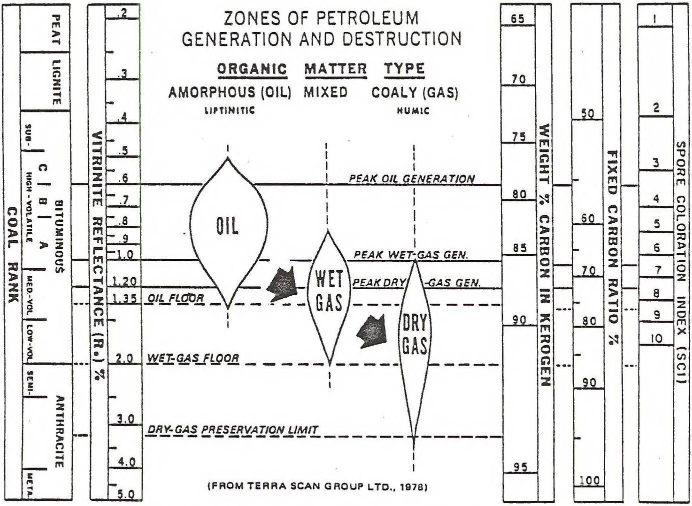
A discussion of the geologic environment of oil and gas deposits can be divided into two major categories: environments of deposition where petroleum source rocks and potential reservoir rocks were deposited; and environment of present-day geological structure where reservoir conditions may favor the existence of exploitable oil fields.

A. Environments of Deposition

Oil and gas are hydrocarbons formed by the action of time and temperature from original organic matter trapped within sedimentary rocks. The following figure shows the relationship of organic matter type, hydrocarbons generated, and thermal maturity indicators which have been developed to determine the maximum paleotemperature experienced by organic sediments. With this empirically derived information, geochemical studies can estimate whether a potential source bed is thermally undermature, mature, or overmature. This information and the Total Organic Content (TOC) of the sediments are the principal parameters used in regional studies of potential petroleum source rocks. In general, sediments containing at least 0.5 percent (by weight) TOC are considered potential source rocks.

The following is a list of those units within the study area which, based on the previous discussion, meet the parameters for a favorable petroleum source rock (from Britt, 1980).

FORMATION	RELATIVE POTENTIAL
Ordovician Vinini Shale	Low to intermediate potential due to limited areal distribution within the study area and intermediate maturation.
Devonian-Mississippian Pilot Shale	Intermediate potential. Good areal distribution and thickness of fair to good source rock quality with favorable maturity.
Mississippian Chainman Shale	High potential due to very large volume of fair to good quality source rock. Favorable maturity with geochemical studies indicating more gas than oil generated.
Pennsylvanian Ely Limestone	Intermediate potential. Good quality source rock with favorable maturity, but limited volume of source bed facies.
Eocene Sheep Pass Formation	High potential. Pyrolitic yield of 29 to 33 liters/metric ton from organic mudstones in wells in Rairoad and White Pine Valleys.



Correlation of coal-rank scale with various maturation indices and zones of petroleum generation and destruction. Relative importance of each petroleum-generation zone depends on composition of original kerogen.

Reservoir rocks are those which show sufficient porosity and permeability to hold commercial volumes of oil and/or gas if a trap is present. The following is a list of the major potential reservoir units within the study area, though numerous other units with local favorable facies probably exist and are not included (from Britt, 1980).

FORMATION	RELATIVE POTENTIAL
Upper Cambrian	Fair in dolomite and limestone.
Ordovician Eureka and Swan Peak Sandstones	High where diagenetic cementation has not progressed to quartzite.
Devonian Simonson Dolomite and Guilmette Formation	High in bioclastic, biostromal, and biohermal "reef" type facies.
Mississippian Diamond Peak Formation (and equivalents)	High.
Mississippian Joana, Desert, Redwall, and Great Blue Limestones.	Fair to good.
Pennsylvanian Ely Limestone	Fair, good in localized sandy facies.
Permian	Fair in both carbonate and clastic facies.
Mesozoic	Good potential only if sections similar to those north and east of the study area are found below thrust plates in western Utah and southern Nevada.
Tertiary: Eocene Sheep Pass Formation	High; production in Eagle Springs fields.
Oligocene Garrett Ranch Formation	High in basal, highly fractured, and vesicular ignimbrites; production from Eagle Springs and Trap Spring fields.

B. Geologic Structure

The study area can be roughly divided into two environments in which oil and gas deposits may be found today. The largest of these is the Basin and Range environment of horst-graben fault blocks where complex fault traps have formed in the down-faulted grabens. In the study area, this environment covers all of the Nevada and Utah portions lying west of the Sevier Orogenic Belt.

All of the production from the study area has come from the Basin and Range environment where angular unconformities and faults form structural traps in the deep valley (graben) portions of the area.

The second major environment of reservoir formation is found in the Overthrust Belt where this "oil province" crosses extreme eastern Nevada and western Utah. This "belt", extending from Canada to Arizona, has only been recognized as a major U.S. oil and gas province in the last 20 years, yet active and new discoveries in this province are rivaling any other province in the nation.

Traps in the Overthrust Belt within the study area can be simple to complex stratigraphic and/or structural in sediments of Paleozoic to Mid-Mesozoic age that have been overridden and obscured by older rocks.

Oil and Gas - Review of Potential

The parameters considered in determining the oil and gas potential of the study area include the presence of source and reservoir beds and their areal distribution, regional thermal maturation levels, negative areas (i.e., calderas, large plutons), and the orogenic belts. Based on these criteria, the study area was divided into areas of high, good, speculative, and low potential.

High potential was assigned to areas having thermal maturity sufficient for oil generation and the overlapping presence of the Eocene Sheep Pass Formation and the porous sand facies of the Mississippian Diamond Peak-Illipah Formation where these formations are underlain by the Mississippian Chainman Shale. Such areas represent the greatest possible source and reservoir bed coincidence with thermal favorability. All production in the Great Basin to date has come from within this area.

No attempt was made to separate areas where the Sheep Pass Formation and other prospective horizons have been removed by recent erosion, but it is recognized that such areas are present within the high, as well as the good and speculative potential areas.

Good potential areas have either the Sheep Pass Formation or the Mississippian units present, but not superposed. Since all but one producing well in the Great Basin is producing from Sheep Pass rocks or immediately overlying Garrett Ranch Group volcanics, this unit is rated good wherever it is present. Mississippian strata represent the best source and reservoir units in the Paleozoic sediments and if a purely Paleozoic oil or gas field is discovered, it is likely to be associated with these strata and be of larger volume than the Tertiary fields. Because of favorable maturity, source bed, and reservoir potential, the area of Mississippian Chainman Shale overlain by the porous sand facies is given a good potential rating.

The speculative category includes areas of the Basin and Range environment where favorable Paleozoic units other than those already discussed are present and also all of the Overthrust Belt (Sevier Orogenic Belt) within the study area. Much of the speculative potential represents areas lacking in past exploration and a general lack of subsurface data to use in evaluating potential.

Low potential was assigned to all caldera areas, large plutons, intense volcanic centers, and areas where favorable host and source beds are absent. In addition, the area south of the line extending from near Tonopah, Nevada, to St. George, Utah, is thought to be overmature in most of the Paleozoic section and is assigned a low potential.

(Note: In reference to the potential of areas for oil and gas, the Fugro results took only stratigraphic considerations into account and not the liklihood of the presence of adequate traps. Phone conversations with Terrance L. Britt (author of the oil and gas technical report for Fugro) and Larry D. Millikan (Fugro exployee who produced the ratings) confirmed that the mountain or horst areas would generally all have a low potential due to the probable absence of structural traps. David L. Eddy)

It should be emphasized that the potential assigned to any given area is based on present knowledge and available data. The intensity of exploration in the Great Basin and Overthrust Belt will likely result in new discoveries which may change the outlines of various units, and would, of necessity, change the potential should a new discovery be made. This interpretation is subject to revision and change as new data become available.

Geothermal - Geologic Environment

Thermal springs and wells may be surface manifestations of large goethermal reservoirs at relatively shallow depth. To define the limits of potential reservoirs, further data on the geologic environment which controls their occurrences need to be analyzed. However, the data are presently not available to delineate the resources within the study area. Therefore, the approach followed in this report is to compile and interpret existing geologic favorability criteria that are believed to govern or reflect the occurrence of geothermal reservoirs. The following geologic favorability criteria are generally accepted by workers in the field of geothermal resource assessment:

- Lineaments:
- Late Tertiary and Quaternary fault distribution;
- Margins of volcanic centers;

- Valley structure;
- Basaltic reheating of water in thick permeable ignimbrite sheets;
- Aeromagnetic data;
- Areas of mercury mineralization;
- Low Richter magnitude (<M=4) earthquakes; and
- Proximity to young silicic volcanic centers.

In the remainder of this section, these criteria are described in terms of geologic factors specific to the study area. Individually, they may not be significant to this study, however, when considered together, they serve to establish a basis for identifying potential areas of geothermal favorability. Four major east-west lineament systems cross the western portion of the study area. These are, from north to south, the Pritchard Station, Pancake Range, Warm Springs, and Timpahute Lineaments. These are important in that they generally coincide with hot springs and volcanic centers.

The mutual intersections of late Tertiary and Quaternary faults, lineaments, and the margins of volcanic centers are significant in that they facilitate heat access to ignimbrite aquifers. This heat access is evidenced in the study area by localization of hot springs. North Delamar and Hot Creek Valleys are examples of such intersection areas.

Asymmetrical valley structure, such as that of Antelope Valley favors hydraulic gradients and recharge relationships necessary for geothermal reservoir longevity. Where such asymmetrical valleys result in downdip hydraulic vectors to late Tertiary or Quaternary faults along mountain fronts and acquifer recharge in areas of sufficient heat source, a geothermal reservoir may occur. In areas adjacent to volcanic centers, compound ignimbrite cooling units in asymmetrical valleys may produce lateral permeability barriers, further favoring the formation of the geothermal reservoir. These conditions appear to be present in the Garrett Ranch Volcanic Group in Railroad Valley. The subsurface data are insufficient to identify with certainty any other asymmetrical valley structures, although their presence is suspected within the study area.

Using the approach of Smith and Shaw (1979) active and extinct volcanic systems can be distinguished on an age versus magma chamber volume plot. The assumption used by Smith and Shaw is that very old but small magma chambers are most probably extinct, while a young, large magma chamber is most likely active. Based on this relationship, the Williams-Hot Creek Caldera Complex at first seems to be an extinct volcanic system, not capable of producing geothermal water; however, aeromagnetic data by Zeitz and others (1978), suggest the presence of basaltic intrusions, possibly along preexisting caldera ring faults. These young basalts, where of sufficient magma chamber volume, could have locally reheated ignimbrite aquifers. The number of possible geothermal reservoirs within the study area produced by reheating from these young volcanic systems is not known.

Mercury is commonly associated with geothermal provinces (Matlick and Buseck, 1976) and is thus considered as an indicator of geothermal favorability.

Low-magnitude earthquakes may document seismic disturbances associated with geothermal activity. Two low-magnitude (Richter magnitude less than 4) earthquake clusters exist in the study area. One cluster south of the Timpahute Lineament concides with a northeast trending Cenozoic fault zone. The seismic activity may be partially related to tectonism along this fault zone. The second cluster, east of Milford, Utah may correlate with the Thermo KGRA (Known Geothermal Resource Area).

The final geologic factor is that of the spacial distribution of silicic volcanic centers. Armstrong and others (1969) and McKee (1971) have shown that the age of silicic volcanism decreases radially from a core area in east-central Nevada. Most of the study area is within the 19 to 40 million-year-old region of silicic volcanism. According to Smith and Shaw (1979), magma chambers of this age are considered extinct except if they are of tremendously large volume (approximately $1x10^6$ km^3). No evidence exists for such large volume magma chambers within the study area. However, the southern part of the study area is in the zero to six million-year-old region of McKee (1971). Magma chambers of this age are generally considered active and may be associated with geothermal resources. The criteria discussed above were used to establish favorability areas for geothermal potential discussed in the following section.

Geothermal - Review of Potential

The favorability criteria indicate that 11 regions within the study area have a high potential for the occurrence of low (<90° C) to intermediate (90-150° C) temperature convection systems of unknown volume. Within the areas of favorability, geothermal reservoirs at depths of less than about 3 kilometers are considered likely to occur. The 11 areas of high favorability for the occurrence of low to intermediate temperature geothermal resources are listed and prioritized (most favorable listed first) as follows:

1. Milford area including Thermo and Lund KGRAs;

2. Railroad Valley;

3. Hot Creek Valley (including Warm Springs KGRA);

4. Sevier Desert (including part of Crater Springs KGRA);

5. Fish Springs Valley:

6. West Stone Cabin Valley;

7. White River Valley;

8. North Delamar Valley;

9. West Pahroc Valley;

10. Antelope Valley; and

11. Quinn Canyon Valley.

Exclusive of the above 11 areas of favorability, numerous thermal springs and wells occur in widely scattered localities throughout the study area. In the vicinity of these thermal sites, the geothermal potential is considered good to speculative. All other areas are considered to have a low potential for the occurrence of geothermal resources.

Oil Shale - Geologic Environment

Prospective Paleozoic black shale units like the Gibellini facies originally formed as siliceous muds, oozes, and slimes high in organic content. Most of this organic matter was derived from marine bacteria, phytoplankton, zooplankton, and to a lesser extent, algae, sponges, shells, higher plants, and humic debris. This organic material was altered during diagenesis to kerogen, a solid, bituminous mineraloid, probably without major thermal degradation. Areas where thermal degradation continued do not have oil shale potential as the kerogen would have altered to liquid hydrocarbons or gas. The most prospective oil shale units, therefore, will be those which were thrust or otherwise elevated soon after deposition, thus preventing deep burial and thermal alteration of kerogen.

These kerogen-rich sediments were deposited in areas receiving large volumes of organic debris derived primarily fron near-surface marine phytoplankton. Such deposition is typical of fairly deep-water (100m) basins lying below wave-base disturbance depth and having anoxic bottom conditions permitting preservation of organic matter (Desborough and others, 1979). It is thought that during diagenesis of these sediments, authigenic sulfide minerals of iron, zinc, molybdenum, and other metals formed.

In various parts of the study area, the environment for deposition of these marine black shales existed during several geologic periods.

A second environment in which oil shale formed was the large Tertiary lakebeds where deposition of organic silts and muds took place in relatively shallow, brackish water. Though shallow water conditions were still anoxic in these still inland lakes, the large oil shale deposits of the Green River Formation (Eocene) in northwest Colorado and eastern Utah are of this type. This environment is seen in some sediments in the Sheep Pass Formation within the study area. These deposits are of Eocene age and are relatively young. They have not been subjected to enough thermal degradation through burial to have transformed the kerogen to hydrocarbon, except in areas of extreme accumulation and burial or in proximity to later volcanic vents or increased local thermal gradient. These shales do not contain associated metals.

Oil Shale - Review of Potential

The potential for oil shale in the study area is difficult to assess. The known presence of low-grade oil shales in the Vinini Shale and Woodruff Formations indicates that these and similar units are prospective deposits wherever they occur in the near-surface or outcrop. Their commercial value, however, may depend on extractable associated metals in the oil shale and the distribution, grade, types, and controls of these metals are not known. Oil shale potential in Eocene Sheep Pass Formation has not been assessed primarily due to lack of exposure of this unit. Continued drilling in the Sheep Pass Basin may delineate areas favorable for oil shale occurrences in the future.

In general, occurrences of Paleozoic oil shale units preserved in the upper plates of thrust faults (i.e., Roberts Mountain Thrust, Sevier Orogenic Belt) have good potential for low-grade oil shale. Areas within the study area that were uplifted soon after deposition, but not eroded and which now lie in the mountains or at the mountain front in the near-surface, also offer potential. Less potential exists in shallow lying Sheep Pass Formation occurrences, since drilling has shown such areas to have been eroded subsequent to Basin and Range faulting. As methods of extraction of oil from oil shale improve, the incentive to explore for and develop low-grade metalliferous oil shales will increase as will the potential of this vast and largely unexplored resource.

Coal-Lignite

There are no commercial deposits of coal or lignite within the study area and no potential for discovery of such deposits is assigned herein. Three subeconomic deposits of low-grade bituminous coal or lignite are known to occur near or within the study area in White Pine County, Nevada, and in Juab and Millard Counties, Utah.

The Nevada occurrence is located in the Pancake Mining District, White Pine County, and is described by Hose, Blake, and Smith (1976) and Horton (in U.S. Geological Survey and others, 1964) as three seams of low-grade bituminous coal contained in interbedded sandstone, conglomerate, and argillaceous, organic shale of the Upper Diamond

Peak Formation of Mississippian age. These seams, having a maximum thickness of 1.8 meters, 0.5 meter and 0.9 meter, respectively, were discovered in 1870 and prospected for about seven years. Two shafts were sunk on the steeply dipping (40°) seams during that time (Horton, in U.S. Geological Survey and others, 1964), but no production figures are available and no work has been done since that time.

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